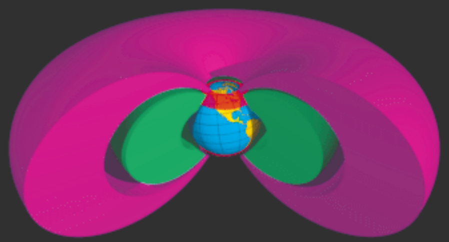
# Data Assimilation and Data Synthesis In Radiation Belt Modeling



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National Space Weather Workshop, February 5-6, 1998

# What does Data Synthesis Mean?

**The Broadest Definition:**

Any model that uses data as in put

- Statistical/Empirical Models
- Input-Output/Predictive Models
- Theoretical/“Physics-Based” Models

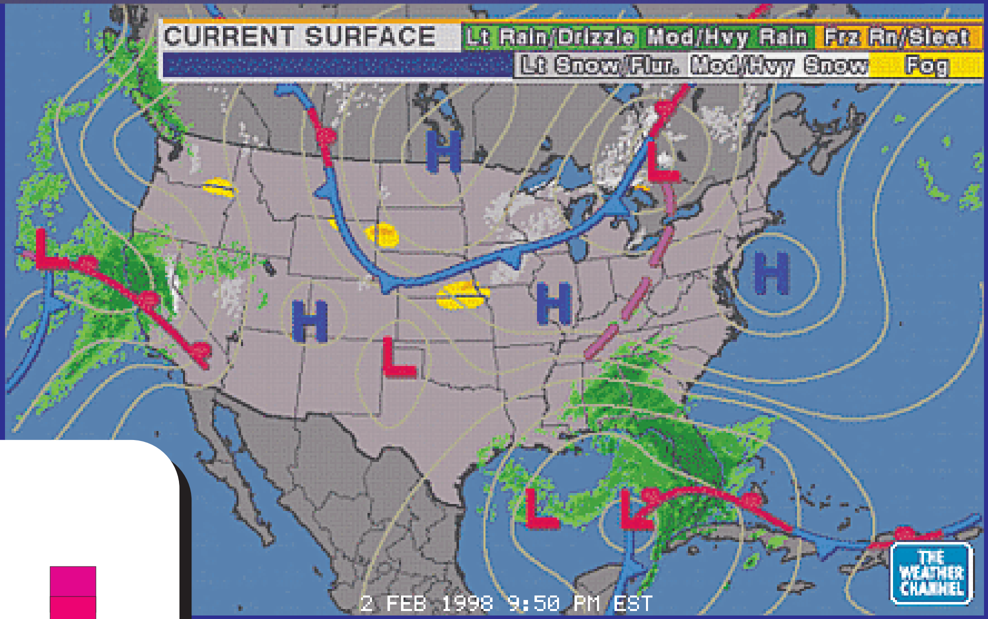
**My Definition:**

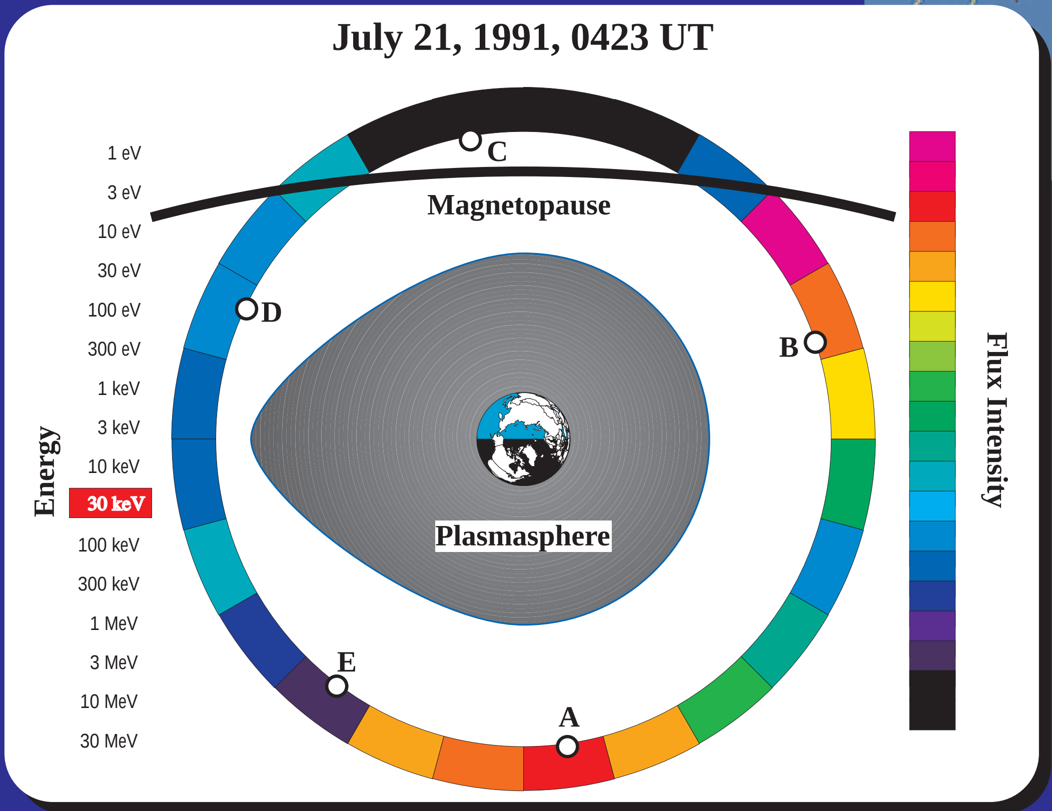
A model that puts together data from a variety of sources, consistent with basic physical principles, in a manner that produces new or enhanced information about a system.

- Global-Average Models
- Time-Dependent “Climate” Models
- Time-Dependent “Event” Models

# The Weather Map Analogy

- Multiple Data Sources
- Large-Scale View
- Locally ≈ Accurate
- Easy Visual Interpretation




Proposed synthesis map for geosynchronous orbit

Reeves, NASA Internet CAN, 1994

# Statistical/Empirical Models

## Examples:

- AE-8, AP-8, solar max and solar min versions
- FSU State Standard (INP-91), based on AE-8 + additional data
- LOWALT, low-altitude extension of AE-8
- UNIRAD, based on AE-8 + LOWALT + additional data
- PL GEOSpace, based on CRRES: dose, protons, electrons, heavy ions
- Proto-Models, statistical analysis, reference events, folklore, etc.

## Properties:

- Combine data over extended times and/or multiple missions
- Describe the average state of the radiation belts
- Significant scatter and/or variation in the input data
- Not generaly consistent with **B** or **E** models, diffusive equilibrium, etc.

# Input-Output/Predictive Models

## Examples:

- Linear Prediction Filters, e.g. Baker et al., 1990
- Neural Networks, e.g. Koons & Gorney 1991
- Wavelet Analysis, e.g. Szita 1996
- State Space, e.g. Detman & Vassiliadis, 1997

## Properties:

- Input is typically solar wind or geomagnetic index
- Output is typically particle flux or geomagnetic index
- Takes into account time history of input and output
- Output usually low-dimensional. e.g. Dst, not 3-D proton fluxes
- Relatively high predictive accuracy
- Could be combined with global synthesis models to provide predictions or extrapolations

# Theoretical/Physics-Based Models

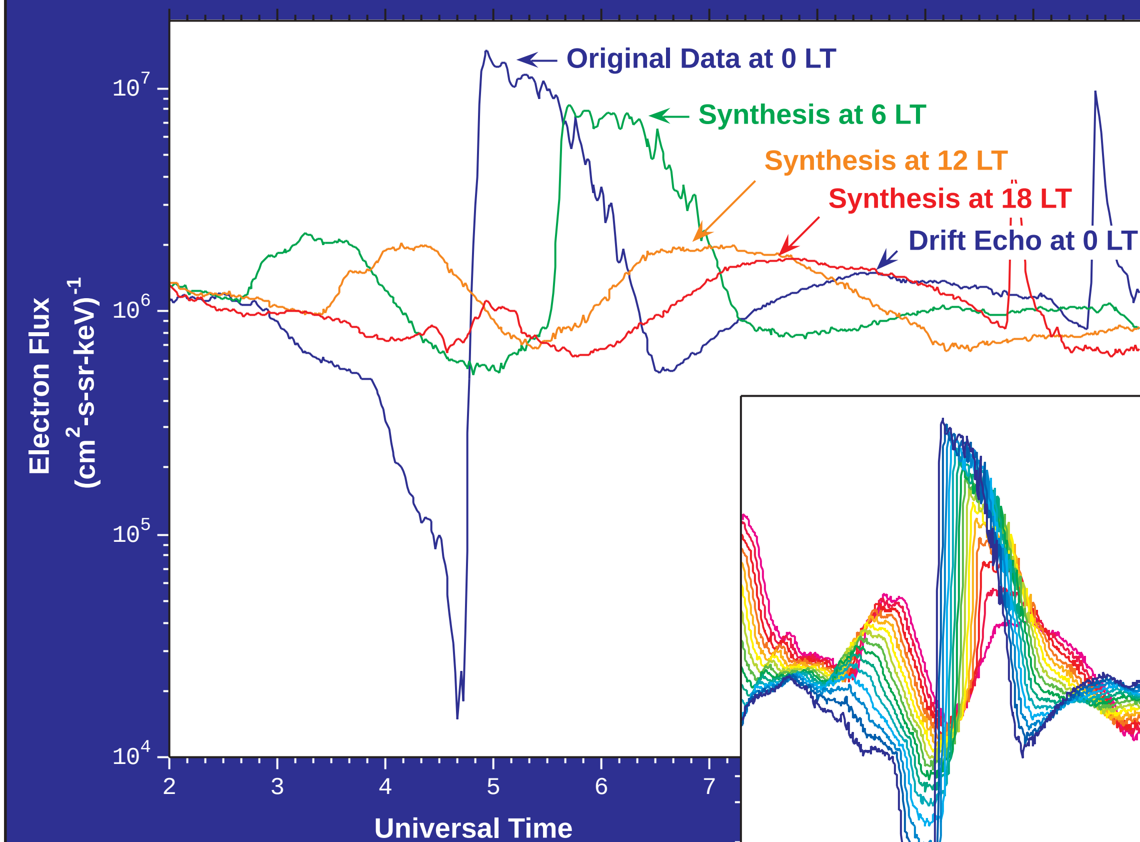
## Examples:

- Rice Models, MSM, MSFM convective drift models
- SALAMMBO, diffusion + convection
- Global MHD Models
- Event Models, e.g. March 1991 event, Li/Hudson et al.

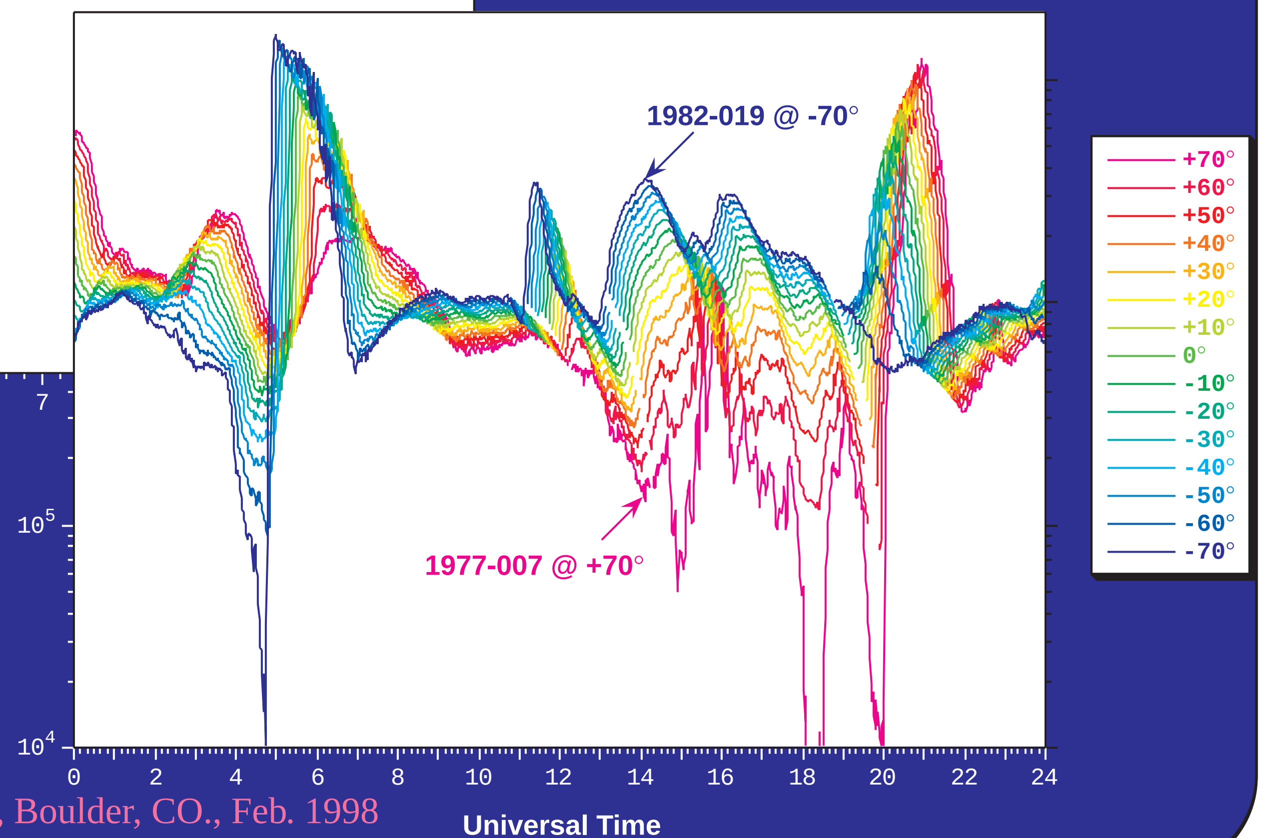
## Properties:

- *Strict* adherence to a set of physical equations
- Data input usually initial conditions or boundary conditions
- Output is high-dimensional. e.g. fully 3-D, full distribution functions
- Typically consistent with internal or external **B** and **E** models
- Typically adhere to “Prime Mover” theology
- Could be run in a predictor/corrector mode to interpolate between data synthesis time steps

# Synthesis/Assimilation Example

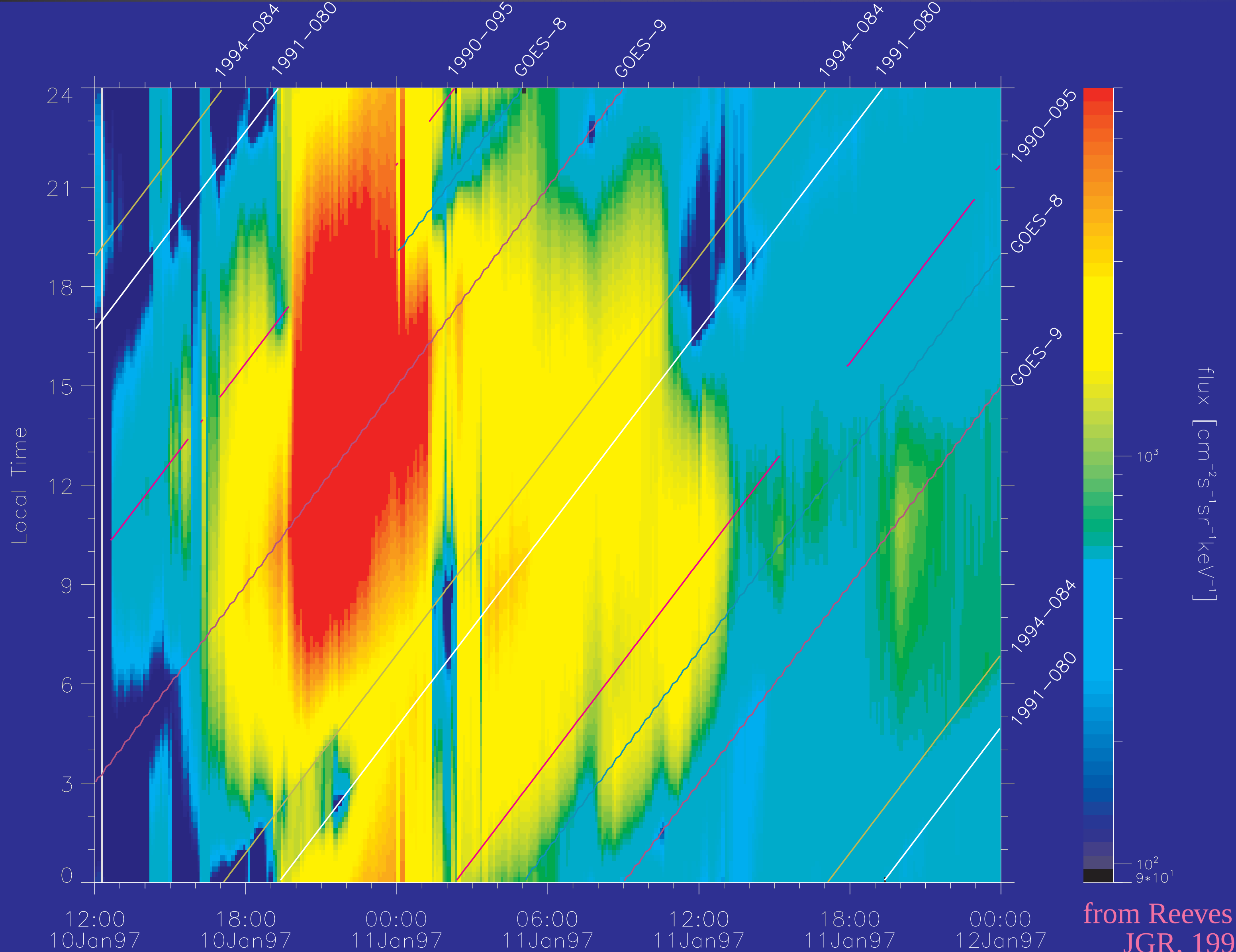



- 3-4 Geosynchronous Satellites
- Linear interpolation based on gradient-curvature drifts
- Fluxes at any UT, LT, or Longitude



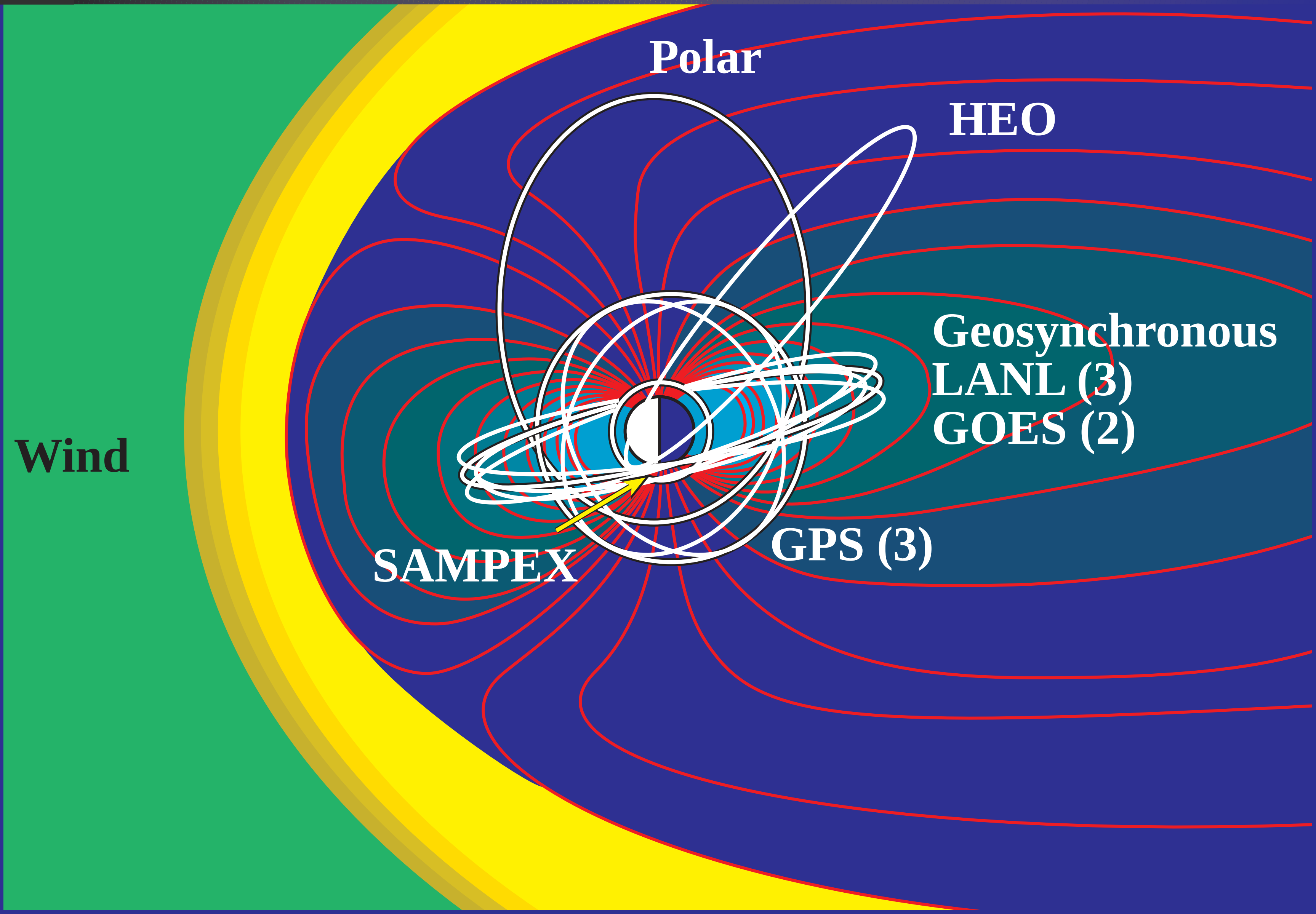

G. D. Reeves, Space Weather Workshop, Boulder, CO., Feb. 1998

# >2 MeV Electrons, January 1997

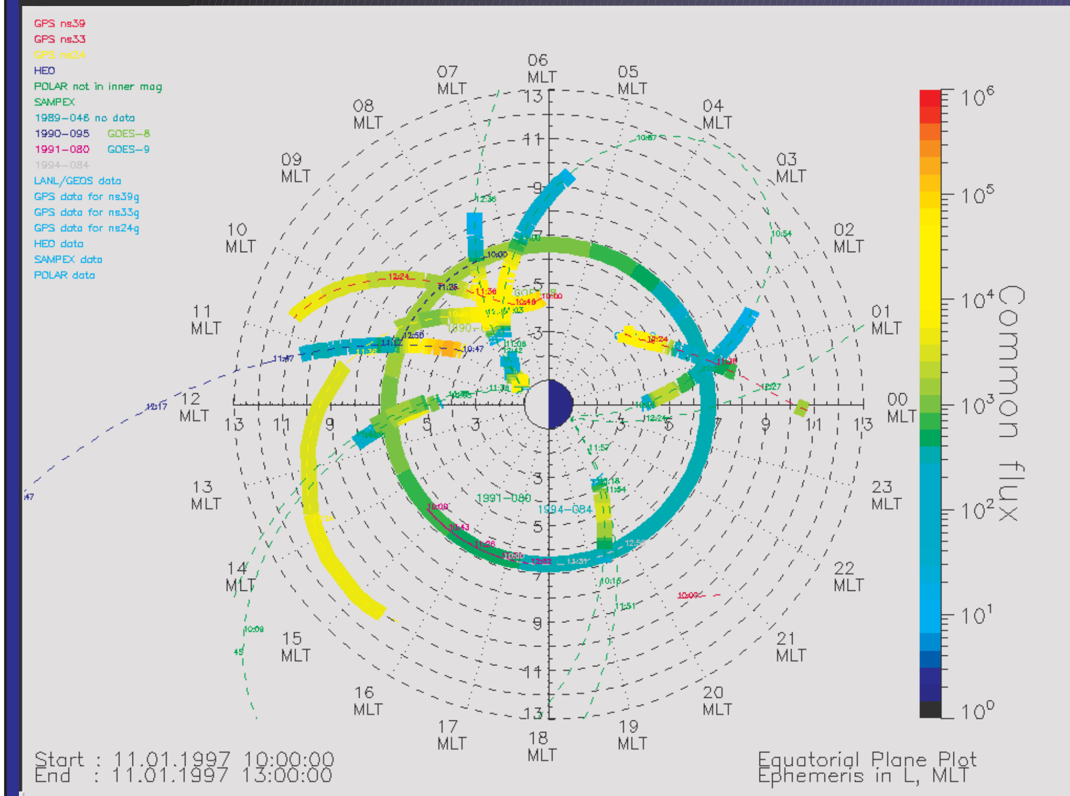



from Reeves et al
JGR, 1998

# Jan. 1997, 11 Satellite Synthesis

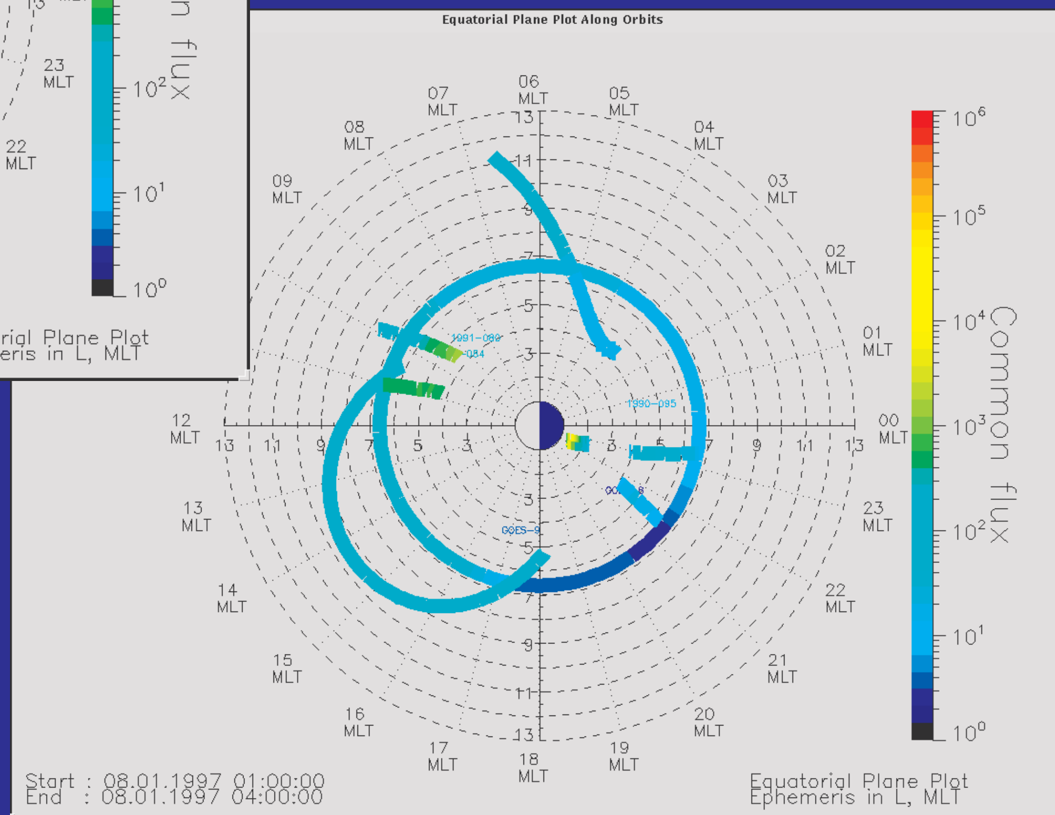


# >2 MeV Electrons, January 1997




- Multi-Satellite Synthesis
- Projection to equatorial plane
- LANL, GOES, GPS, HEO, POLAR, SAMPEX

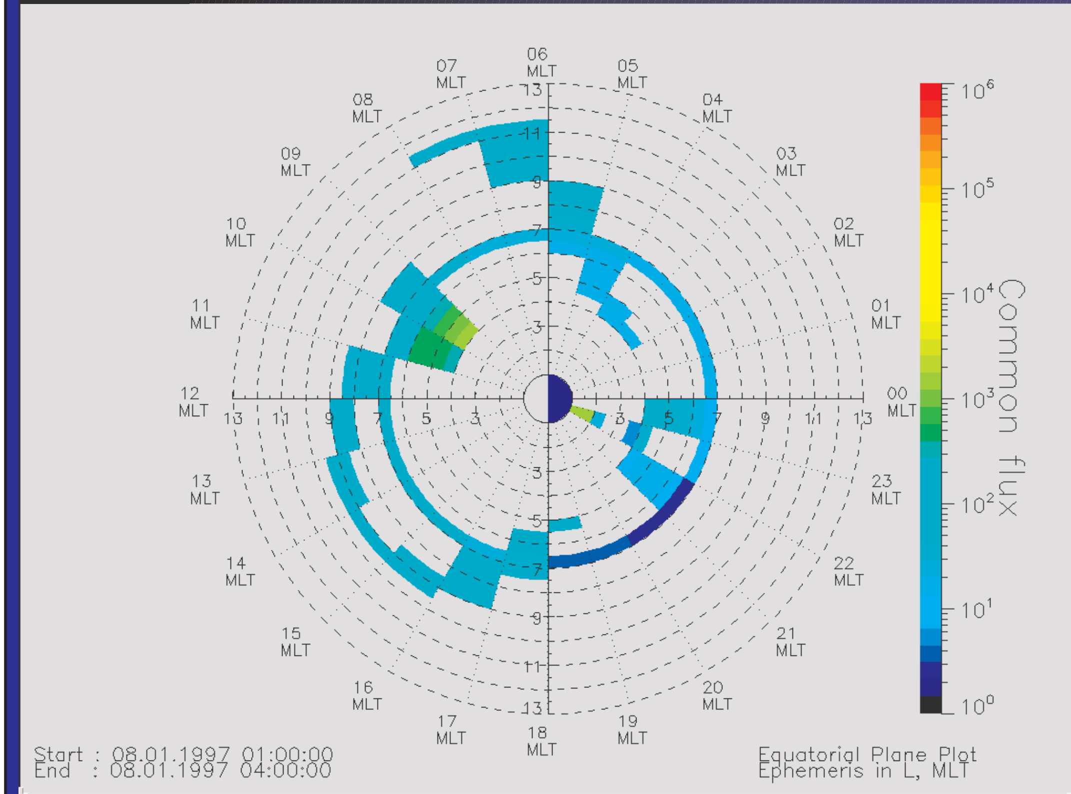
Active Interval




Quiet Interval

G. D. Reeves, Space Weather Workshop, Boulder, CO., Feb. 1998

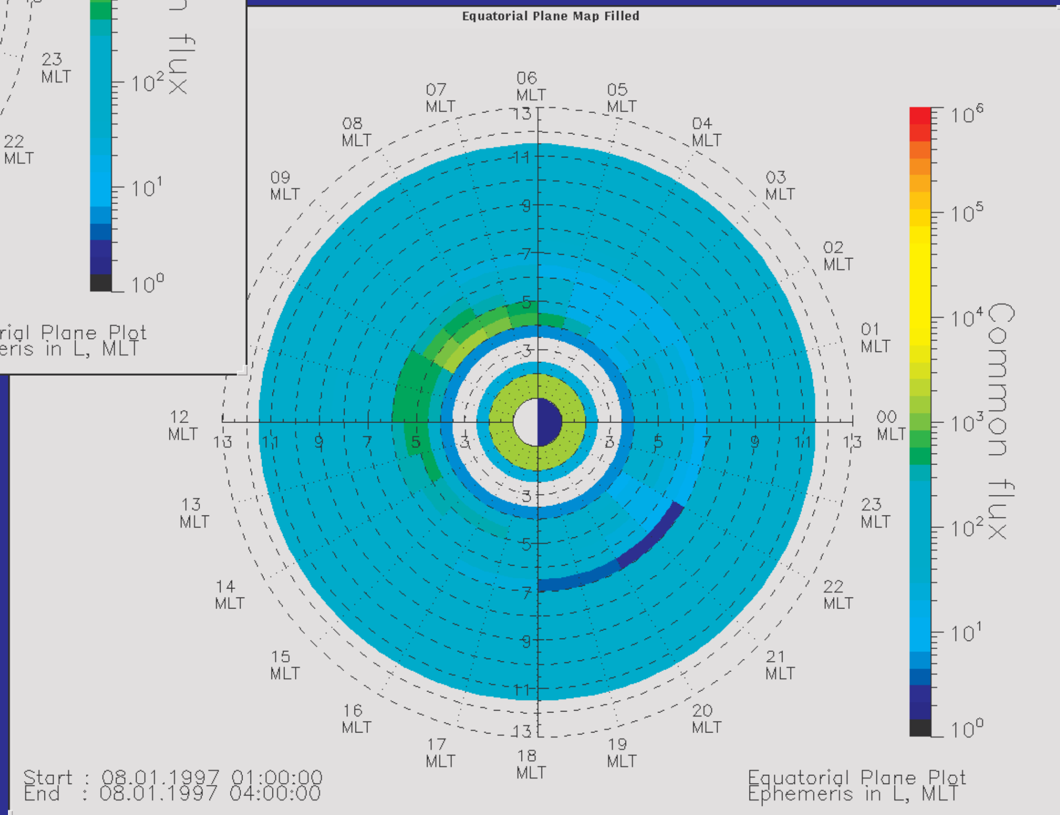
# >2 MeV Electrons, January 1997




- Data binned in L and MLT
- Linear interpolation in MLT
- Produces nearly complete coverage in ≈3 hr intervals

Binned in L and MLT

Complete Synthesis




G. D. Reeves, Space Weather Workshop, Boulder, CO., Feb. 1998

# Limitations

- Temporal, Spatial, & Energy Coverage
  - What epoch does the model apply to?
  - What energy ranges?
  - What coordinates is the model output available in? And what are the implicit assumptions (e.g. B model)?
- Data Requirements
  - e.g. B, pitch angle, energy, spatial coverage
  - Strict data requirements limit what data sources can be used
- Calibration issues
  - A major effort when combining data from different sources
  - Even with perfect calibration: angular coverage, energy passbands, $\Delta T$
- Accuracy of output: especially for extreme events
  - How strictly should output match input?
  - How much scatter is there in a single model bin? (e.g. Tsyganenko)

# Conclusions

- All Approaches Show Significant Promise:
  - Theoretical/Physics-Based - MSFM, GGCM
  - Input-Output/Predictive - State Space Models
  - Statistical/Empirical - GEOSpace, NASA, LANL/ISTP
- No data assimilation / data synthesis models are being run or tested on a regular basis.
- Basic “weather map” synthesis models of the radiation belts could be produced and run today. This would provide a baseline against which to measure progress.
- Synthesis models of one type can be combined with other techniques such as linear filters, MHD, convective models, etc. to provide further functionality such as spatial and temporal interpolation or predictions of future conditions.